APPENDIX E

HISTORY, USES, AND EFFECTS OF FIRE IN THE APPALACHIANS

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History of Fire in the Southern Appalachians

For millions of years before Indians arrived in America, lightning-caused fires were a major environmental force shaping the vegetation of the southeastern United States. Lightning served as a mutagenic agent and as a factor in natural selection which forced species to adapt or perish (Komarek 1974). These lightning-fires were primarily summer fires and burned extensive acreages. Before man, lightning-fires created and maintained the pine grasslands of the southeast, as well as influenced the broad, adjacent ecotones which included hardwood vegetation (Komarek 1965).

Forests of the southern Appalachians probably did not burn as frequently as the pine-grasslands of the adjacent Piedmont. However, there can be no doubt that they did burn periodically. Fires in the pine-grasslands would burn until stopped by weather or the moist fuels of cooler aspects in steep terrain. Depending on the frequency of summer fires, Appalachian forests along this broad ecotone could have been much more open than at present. Komarek (1965) convincingly argues that the natural accumulation of fuels in grasslands, in the absence of grazing, would allow summer fires caused by lightning to burn with sufficient intensity to maintain grassland or a herbaceous understory beneath open forests. Winter fires, which burn with low intensity, fail to prevent the invasion of hardwoods into grasslands.

The mechanism by which lightning causes forest fires is described by Taylor (1973): "A lightning discharge striking and rupturing a live conifer produces and ignites a mixture of volatile extractives and finely divided bark, wood, and needle particles (3 mm dia.) to an intense, short-lived (1 sec.) ball or column of fire which in turn ignites flash fuels in the tree crown or on the forest floor." Only a small percentage of wildland fires in the Southeast are now caused by lightning; most are man-caused. Komarek (1974) states that lightning strikes in the Appalachians were frequent enough to cause the development of species dependent upon fire for most of their reproduction. Zoebel (1969) emphasizes that fire has played a major role in the evolutionary development of table mountain pine, a species with serotinous cones which open and release seed when heated by fire. In fact, many, but not all, natural pine stands in the southern Appalachians develop after the canopy is opened by fire (Barden and Woods 1976; Whittaker 1956).

Thus, there is evidence that fire caused by lightning did play a role in affecting composition of Appalachian forests. However, that role, which was unchanged for 65 million years, was dramatically altered with the advent of aboriginal man in America. About 30,000 to 40,000 years ago, man migrated across the Bering Straits and followed a pathway of grasslands southward down the continent (Komarek 1965). The frequency of fires increased dramatically upon the arrival of Indians to the southern Appalachians about 10,000 years ago (Keel 1976). Although man learned how to produce fire 10,000 to 20,000 years ago, the job of making fire with a fire drill was laborious. This task was so difficult that Indians did not extinguish their campfires, and as a result, many forest fires were started accidentally (Stewart 1963).

Indians purposefully used fire for many reasons. For most of the millennia that they occupied the southern Appalachians and their periphery, Indians were hunters and gatherers. They did not begin to practice part-time agriculture until perhaps 800-1000 A.D., when corn and beans were first cultivated in the southeastern United States (Hudson 1982). They continued to hunt and often used fire to surround and drive game. Hudson states that Indians burned the woods for reasons other than hunting. Burning reduced threats of dangerous forest fires, cleared underbrush which kept forests open, improved habitat for deer and buffalo, and made gathering of acorns and chestnuts easier. The practice of regular burning created large open meadows with widely spaced trees and abundant wildlife. Fires set by Indians burned during the fall and winter primarily, and differed from the more intense summer fires caused by lightning.

Wherever there were Indians, surely there was fire (Stewart 1963). The Shenandoah Valley of Virginia was a vast prairie between the Blue Ridge Mountains and the Alleghenies in the mid-1700s. At the time, it was fired annually by the Indians to keep it from reverting to woodland (Leyburn 1962). The prairies to the west of the Alleghenies were also maintained by repeated Indian fires. Certainly some of these prairie fires moved into the mountains. Southeastern Indians lived along the fertile river bottoms in the mountains and built their villages on bluffs of ridges above the flood plain (Hudson 1982). The location and occasional relocation of Cherokee villages were probably governed by the availability of riverside land and the supply of firewood in narrow Appalachian valleys. Their burning along these river systems would have left the mountain forest adjacent to these streams and their habitations more open than they are today. Although portions of the southern Appalachians were not prime hunting grounds, the Indians had major trails along rivers through these areas, such as the New River in Virginia and West Virginia. Escaped campfires would probably have caused much of these little-hunted areas to burn as Indians traveled between hunting and trading areas.

Some parts of the southern Appalachians were not burned. Captain John Smith in 1608 was told by a member of the Mannahoac tribe of northern Virginia that little was known of the land beyond the mountains because the woods were not burned (Mooney 1894). However, the fact that Spanish explorers with their armies of men and herds of livestock traversed the southern Appalachians in the 16th Century can only be explained by open conditions in the understory of Appalachian forests due to fire. In addition, the presence of buffalo and elk, which are grazing animals, is circumstantial evidence of frequent burning by Indians to maintain suitable habitat for these animals.

Settlers began moving into the mountains of Virginia in numbers in the mid 1700s after the Piedmont became more heavily settled (Trimble 1974). At that time, the Piedmont of the Carolinas, Georgia, and Alabama was still very sparsely occupied. By the early 1800s, the Piedmont of these states was filling and settlers moved into the mountains for land. The Cherokee, however, still clung to their hunting grounds until 1836, when the government removed most of the remaining Indians to Arkansas on the Trail of Tears.

The better land along the major streams was first settled. Brender and Merrick (1950) described the settlement of Mulky Creek in the north Georgia mountains where the first hay crop was harvested beneath the open timber of a south slope. The woods were open with little undergrowth. Broomsedge grew shoulder-high on the drier sites and wild legumes were abundant. This description by Brender and Merrick emphasizes the role that fire must have played in maintaining open mountain ecosystems even before grazing of livestock became a supporting factor. Of course, not all areas of the southern Appalachians were settled evenly. More remote areas away from habitations were probably not burned as frequently as more easily accessible areas. Eventually, however, settlement of the entire southern Appalachian region occurred, and annual burning was the standard practice wherever grazing animals were kept.

Frequent burning by settlers stimulated the production of forage for livestock and retarded the advance of woody undergrowth. Plowing was confined to the flatter bottoms where soil movement was minimal. Evidence indicates that these understory burns had no adverse effect on soil erosion (Glen 1911). However, as good bottomland became scarce, people began cultivating crops on steeper slopes and the land became overgrazed. More land was cleared of timber. Large white pines and yellow-poplars were found on the cooler sites, big yellow pines were found on the drier ridges, and white oaks were abundant in many areas (Brender and Merrick 1950). As the land became more heavily used, erosion of topsoil increased. Settlers struggled to make a living. Making and selling "moonshine" was the major economic endeavor of many of the mountaineers in the late 1800s (Brender and Merrick 1950). The land became worn and often abandoned.

As cotton farming increased in the Piedmont, the use of woods fires increased to control the bole weevil. Even though these fires did little to halt the spread of the weevil, woods burning by cotton farmers was also an annual event (Dorn and Derks 1988)

During the late 1800s, timber companies began buying large tracts of land. Following logging, the slash was often burned and the land was regrazed. In parts of the southern Appalachians, the combined effects of grazing and burning probably eliminated woody reproduction. The grazing history of the Toccoa Experimental Forest in north Georgia suggests that development of reproduction was adversely affected by the browsing of sheep and goats and mast consumption by hogs (Brender and Merrick 1950). The combination of grazing and fire apparently eliminated reproduction which would have been available to replace old growth as it was harvested or died from various causes. However, in most parts of the Appalachians, woody reproduction was apparently plentiful enough to reproduce a stand. Annual winter burning for even 40 consecutive years does not eliminate hardwood root stocks in the Coastal Plain (Langdon 1981; Waldrop and others 1987). Although hardwood root stocks would remain viable under a regime of frequent winter fires, sprouts could not develop into a new stand unless burning was stopped until the trees became tall enough to resist top-killing. Even the pines could not reproduce under a regime of annual fire.

In the 1920s, the U.S. Forest Service was opposed to the use of fire in the woods (Pyne 1982). Even light burning was prohibited on the recently established national forests. The Forest Service and newly formed state agencies unwittingly sought to create an environment totally different from that known by Indians and early settlers in the mountains. Forestry, or at least the phase of forestry that involved regeneration of new stands, created the necessity of fire exclusion. Foresters at that time did not see the benefits of fire nor the fact that fire had played a major ecological role in the development and maintenance of the ecosystems they were trying to protect. Despite their efforts, however, the woods continued to be burned because a long-standing tradition would not die easily.

Gradually, foresters became more enlightened to the role of fire in forested ecosystems. H. H. Chapman of Yale University advocated the use of prescribed fire under carefully chosen conditions for fuel and weather in the management of longleaf pine. Stoddard (1931) published his important study showing the importance of prescribed fire in the management of bobwhite quail. The role of prescribed fire in reducing the hazards of disastrous wildfires was realized after major fires in the South during the droughty 1930s and 50s. The value of fire to prepare seedbeds and sites for planting gradually became evident from research throughout the South.

Controlling understory hardwoods in pine stands, reducing fire hazard, improving wildlife habitat, and preparing sites for seeding and planting are commonly accepted applications of prescribed fire today. However, the use of fire in the Southern Appalachians is not as advanced as in the Coastal Plain and Piedmont, and fire is no longer the dominant factor in the mountains.

Use of Fire to Accomplish Management Objectives

Types of Prescribed Fires

Prescribed fires are generally one of three types: head fires, backing fires, and flanking fires (Brown and Davis 1973). Head fires burn with the wind or upslope. They are of relatively high intensity and move through fuels at a relatively high rate of speed. Head fires are often ignited in strips (called strip headfires) to speed the burning process and to provide the desired intensity. Fire intensity increases as the rear of a previously ignited strip merges with the advancing front of a subsequent strip.

Backing fires back into the wind or burn downslope. They burn with lower flame heights, or lower intensity, and move through the stand at slower speeds than head fires. Backing fires, because of their lower intensity and slower speeds, are more easily controlled.

Flanking fires are set parallel to wind direction and moving into the wind. They are generally used to supplement other burning techniques. For example, flanking fires can be used to speed the process of burning with backing fires. Flanking fires are set perpendicular to backfires. Where flanking fires merge, fire intensity increases.

Fire Intensity, Residence Time, and Fire Severity

Fireline intensity is the heat output of a unit length of fire front per unit of time (Deeming and others 1977). Fireline intensity is directly related to flame length, a readily observable feature of a fire. Intensity is a major factor determining mortality or damage to both understory and overstory hardwoods. As trees grow larger they become more resistant to fire because their crowns are above the heat of the flames and thicker bark provides greater insulation to the cambium. Thus, hotter fires are necessary to kill or damage larger trees.

In addition to fire intensity, the duration of exposure or residence time is an important consideration when planning a prescribed fire. Protoplasm can be instantly killed at a temperature of 147°F, but also can be killed by prolonged exposures to lower temperatures (Hare 1965; Nelson 1952). Backing fires of low intensity can be lethal to small stems because their slow speeds enable lethal cambium temperatures to be reached just above ground. Conversely, where understory stems are larger and have thicker bark, head fires are likely to be more lethal than backing fires because of damage to the crowns.

It is important to appreciate the difference between fire intensity and severity. Fire severity describes the condition of the ground surface after burning (Wells and others 1979) where fire intensity is the rate at which an on-going fire produces thermal energy. Although the two terms can be closely related, they may also be unrelated. For example, a burn that consumes all the organic layer and alters mineral soil structure and color would be classified as a severe burn. A high-intensity fire in heavy fuels that burns when the soil and forest floor are moist would leave a large amount of residual forest floor and not alter soil structure and color. Thus, in this example, a high intensity fire would be classified as of light severity.

Hazard Reduction Burning

Arson remains a serious problem. Fires set by arsonists are difficult to control because they often occur during times of extreme fire danger. Wildfires in recently harvested stands in steep terrain are extremely dangerous because of heavy fuel loadings, ranging up to 50 tons/acre (Sanders and Van Lear 1987). Wildfires in these fuels are intense and may ignite numerous spot fires far away from the main fire by burning embers carried by the convection column.

An understory of hardwoods, shrubs, and vines often develops in Appalachian pine stands. When draped with pine needles, this understory becomes highly flammable and, if ignited under adverse weather conditions, could destroy the overstory pine stand. This understory fuel complex is called a "rough", and if it extends over a large area the whole forest is at risk to destruction by wildfire. In hardwood stands, rhododendron and mountain laurel often form thickets of highly flammable fuels which allow fire to climb into the canopy.

Prescribed fire can be used for hazard reduction, or reduction of dangerous fuels to protect the forest from wildfire. Recent studies in the Appalachian mountains in South Carolina have shown that broadcast burning of logging slash under proper weather and fuel moisture conditions can reduce highly flammable woody fuels following clearcutting by over 90 percent (Sanders and Van Lear 1987), thus rendering recently logged areas fireproof.

In some regions of the southern Appalachians, hazard reduction burns are conducted in mature stands. These low-intensity burns are ignited under appropriate conditions in the winter, especially along roads where arson is most common. After a hazard reduction burn, the forest is safe from wildfire until the next leaf fall and potential damage from wildfires will be small for several (3-7) years.

Understory Hardwood Control

The size, but not the number, of hardwood stems in understories can be controlled by the frequency and timing of prescribed fires (Thor and Nichols 1974; Waldrop and others 1987). Low-intensity fires are generally effective in top-killing most hardwood stems up to 3 inches in diameter. Summer fires are more effective in killing hardwood rootstocks than are winter fires. However, numerous summer fires in successive years are necessary to kill rootstocks and eliminate hardwoods from the understory. It is practically impossible to eliminate hardwood rootstocks with annual winter burning. After 40 annual winter burns on the Santee Experimental Forest in South Carolina, hardwood sprouts were more numerous, although smaller (less than 3 ft), than on unburned plots (Waldrop and others 1987). Although not documented, frequent understory burning in pine stands in the Appalachians would likely have similar effects. Spring fires may be even more effective in killing hardwood rootstocks than summer fires (Phillips and Abercrombie 1987).

In most cases, it is not the goal of forest management to eliminate hardwoods from pine stands. This practice is not economically feasible and is not ecologically desirable. However, periodic prescribed burns are used to control the size of hardwoods, thus reducing wildfire hazard and facilitating stand regeneration. Periodic burning at about 5-year intervals will effectively control the size of sprouts that develop from the top-killed rootstocks. By controlling the size of the hardwood understory, pines can be maintained on those sites where they are best suited and are the most economical crop to grow.

Controlling understory hardwoods with prescribed fire is normally thought of as a silvicultural tool used in pine management. However, there is some evidence that prescribed fire can be used in mature hardwood stands to control the composition of advance regeneration, the seedlings and sprouts that develop in the understory of mature stands. Thor and Nichols (1974) found that the number of oak stems, as well as oak sprout clumps, was increased by both annual winter burning and periodic burning on the Highland Rim in Tennessee. Langdon (1981) noted that rootstocks of oak were more resistant to fire than those of competing hardwood species in the Coastal Plain. These studies have important implications to a major silvicultural problem in Appalachian hardwoods, the regeneration of oaks on good quality sites. There is no doubt that many of the oak stands that currently occupy better sites in the Appalachians became established 60-100 years ago when burning and grazing were prevalent practices.

Some researchers feel that the exclusion of fire and other disturbances has altered the ecology of oak stands on better sites by reducing advance regeneration of oak. Much more research will be needed before foresters can feel confident in using fire to manipulate understory species composition in hardwood stands.

Pine Regeneration

Natural regeneration of pine

Prescribed fire is often used to prepare pine seedbeds. Fires used to prepare seedbeds are usually done prior to harvest. Such burns are of low intensity because fuel loads are much less than those created by harvesting. Low-intensity fires are necessary to protect trees that will furnish seed or shelter. To avoid damage to overstory trees, it is sometimes necessary to reduce fuel loadings with one or more winter burns before a final summer burn is used to prepare the seedbed and knock back understory hardwoods. Dormant season logging further enhances seedbed preparation and allow seed to germinate the following spring.

If logging is scheduled for the spring or summer, it is better to delay the final burn until after harvest. A burn just prior to harvest at this time of year would destroy recently germinated pine seedlings and give hardwood sprouts a year's head start over pine seedlings that would become established the following spring.

Pine plantations

Site preparation burns are normally conducted in the summer and are of moderate to high intensity. They are used to reduce logging debris, control hardwood sprouts, and improve the plantability of the site. Because of their intensity, burns must be conducted under the proper fuel and soil moisture conditions to prevent damage to the forest floor and fine root mat are left, erosion is not accelerated after bu logging debris on slopes up to 45 percent (Van Lear and Danielovich 1988). of broadcast burning in steep terrain on erosion have not been documented.

Broadcast burning late in the summer following long periods without rain can completely remove organic layers from the soil. Such burns effectively redu logging debris ensuring that the site will be plantable, but they can cause damage from accelerated erosion and loss of nutrients and organic matter. I addition, severe burns may contribute to poor initial survival of planted se because of the loss of mulching effects of a residual forest floor. Both on off-site damage from broadcast burning can be minimized by burning earlier i summer soon after soaking rains.

Hardwood Regeneration

Research on the use of fire for hardwood regeneration is limited, primarily of foresters' concerns about damaging stem quality in high value stands. Mu information on bole damage comes from early studies of wildfires (Abell 1932 and others 1933), although a recent study indicated that prescribed fires of moderate intensity in the spring can result in a high percentage of stem dam (Wendel and Smith 1986). However, Sanders and others (1987) found that low- winter backing fires in mature hardwood stands had little adverse effect on trees.

The potential for damage to boles of thin-barked hardwoods by moderate to hi intensity fires is readily evident in the many cat-faced trees throughout Ap forests. However, the role of low-intensity prescribed fires in manipulatin regeneration and the use of higher intensity broadcast burning for promoting coppice regeneration deserves greater attention from fire research. Research now beginning to realize that most hardwood species evolved under a regime o frequent burning (Komarek 1965) and that prescribed fire may be a useful too hardwood management (Van Lear and Waldrop 1987). At present, research resul use of fire for hardwood regeneration are limited to the mixed-oak, cove har and pine-hardwood cover types.

Today it is recognized that even-aged management of oak types is necessary a regeneration can be accomplished by techniques similar to those used for oth intolerant types (McGee 1975). Clearcutting and shelterwood cutting are acce regeneration techniques but advance regeneration is required for oaks to com other species in the understory (Roach and Gingrich 1968). Quantities of ad sized advance oak regeneration sufficient to comprise a major component of t regenerated stand are often difficult to obtain, especially on better sites. (1972) suggests that a minimum of 435 oak stems per acre over 4.5 feet tall required for successful regeneration.

Exclusion of fire or other disturbances from mature oak stands may have alte ecology of these stands to the detriment of advance oak regeneration (Little Van Lear and Johnson 1984). Two studies conducted in the Northeast (Swan 19 Niering and others 1970) and one in the southern Coastal Plain (Langdon 1981 that seedlings of oaks are less susceptible to root kill by fire than other thus giving oaks an ecological advantage. Thus, periodic burning may play a role in promoting advance oak regeneration. Fires every 2 years or more may be the key to oaks becoming dominant over their associates in the advance regeneration pool. However, the exact combination of season, frequency, and number of burns to promote advance oak regeneration in the Appalachians has not been determined.

Several studies support the theory that multiple prescribed burns are necessary to promote advance oak regeneration prior to harvest. Thor and Nichols (1974) found that advance regeneration of oaks in central Tennessee was doubled by both annual (for 6 years) and periodic (2 burns, 5 years apart) prescribed fires. Carvel and Tryon (1961) reported large increases in advanced oak regeneration in West Virginia where stands had been burned several times over a 20 year period. Keetch (1944) found that oak sprouting was stimulated by a single prescribed fire and was maintained by three successive fires.

Single prescribed fires have little effect on species composition in the understory. Johnson (1974) reported that a spring fire in a 102-year-old northern red oak stand failed to increase oak abundance in the understory. The fire also failed to control competing vegetation and killed 58 percent of the existing seedlings. Wendel and Smith (1986) reported no increase of advance oak regeneration after a single spring burn in a central Appalachian oak-hickory stand. The fire caused severe damage to the boles of overstory trees and increased competing vegetation. Teuke and Van Lear (1982) found only slight benefits to oak regeneration after single winter burns in western South Carolina and northeastern Georgia.

Oak seedlings may be more readily established on burned areas. Healy (1988) states that blue jays, a major hoarder and scatterer of acorns, seek out areas of thin litter, low vegetation, and full sunlight to bury the nuts. Galford and others (1988) found that numbers of certain weevil and beetle species that prey on germinating acorns were reduced on burned seedbeds. Results of these studies emphasize the need for further research to elucidate the role of fire in oak regeneration.

The task of regenerating oaks, particularly northern red oak, is more difficult on cove sites than on upland sites. On moist and fertile cove sites, understory vegetation competes vigorously with oak seedlings and usually overtops them. Therefore, advance regeneration of desired species is required. In addition, some control of the subcanopy and midstory is necessary to favor advance regeneration. Recent research suggests that fire exclusion from cove sites has created environmental conditions unsuitable to oak regeneration (McGee 1979). However, research on the use of periodic fire for regenerating cove hardwoods is lacking (Van Lear and Waldrop 1988).

While fire has not been proven to promote oak regeneration on cove sites, it has been successful for regenerating yellow-poplar. This species has adapted to fire disturbance by developing light seed which is disseminated by wind and gravity and germinates rapidly in fire-prepared seedbeds. Yellow-poplar seeds also remain viable in the duff for approximately 10 years and then germinate rapidly after a fire (McCarthy 1933). Sims (1932) found that yellow-poplar seedlings were more numerous in clearcut and unharvested stands that had been burned than in similar stands that had not been burned. Shearin and others (1972) noted that the number and height of yellow-poplar seedlings were significantly increased on Piedmont sites three growing seasons after a low-intensity winter burn on a clearcut area. Viable seeds stored in the duff before burning accounted for the large number of seedlings after burning.

While forest management is traditionally aimed at pure pine or mixed hardwood stands, a new site preparation technique using prescribed fire in combination with properly-timed felling of unmerchantable trees has been demonstrated to be effective in regenerating pine-hardwood mixtures in the southern Appalachians. This method is commonly described as the "fell and burn" technique (Abercrombie and Sims 1986; Phillips and Abercrombie 1987) and consists of two steps. After clearcutting hardwood or pine-hardwood stands, residual stems over 6 feet tall are felled with chainsaws. Felling is conducted during early spring following full leaf development when carbohydrate reserves in the roots are low. The presence of leaves on the felled trees speeds the drying of small twigs and branches which serve as fuel for the broadcast burn, the second step of the process. Burning is conducted in mid summer within 24-48 hours after a soaking rain, ensuring that a residual forest floor and root mat will provide protection against erosion and that heat penetration of soil will be minimal. Pine seedlings are planted at a wide spacing the following winter and can successfully compete with hardwood coppice.

Use of this technique allows planted pines to become established by controlling hardwood growth (Danielovich and others 1987). Pine survival is generally over 90 percent the first year after planting and over 75 percent after 4 years (Phillips and Abercrombie 1987). In three stands planted with shortleaf pine, oaks were numerous but much shorter than pines. Oaks were generally less than 6 feet tall while pines averaged over 8.5 feet.

Summer broadcast burning is probably the more beneficial of the two steps used in this site-preparation technique. Sprouts that developed after chainsaw felling are top-killed and new sprouts are less vigorous. Burning removes over 65 percent of the woody fuels less than 3 inches in diameter (Sanders and Van Lear 1987), making the site more accessible for planting. After planting, the black surface makes green seedlings more visible, thus ensuring a better job of planting. Aboveground buds on hardwood stumps are killed by fire, forcing new sprouts to originate from below ground ensuring that they are better anchored and of better form. Burning also controls rhododendron and mountain laurel thickets, thus providing a significant increase in the amount of plantable area in a stand.

Protection of Threatened and Endangered Species and Unique Plant Communities

Special consideration for threatened and endangered species must be given when planning any prescribed burn. Although not well documented in the literature, habitat for some of these species may be eliminated by prescribed burning. However, other threatened and endangered species require fire to become established and survive. For example, mountain golden heather, turkeybeard, sand myrtle, and twisted-head spike-moss grow on ledge habitats in the Appalachians which were created and kept open by natural fires and severe weather. The U.S. Forest Service is conducting research on the use of fire to maintain these sensitive habitats (Morse 1988). The role of fire in the ecology of many threatened and endangered species is not well understood.

Fire has played an essential role in maintaining pine ecosystems in eastern North America (Spurr and Barnes 1980). Although not currently threatened or endangered, table mountain pine is being replaced by more shade-tolerant hardwoods in the Appalachians because of the exclusion of fire. This species is adapted to regenerate following intense fires because it has serotinous cones which release seed after they have been heated by fire. Researchers in the Great Smoky Mountain National Park are exploring the use of fire to maintain this species.

Some researchers feel that the grassy balds on the summits of high Appalachian peaks may have been created and maintained by fire (Clements 1936). However, other researchers have attributed their occurrence to other factors such as insect attacks, disturbance by Indians, or climate. Whitaker (1956) regards these grassy balds as a climax type of vegetation developing under conditions of extreme exposure. Further research is needed to document the role of fire in maintenance of grassy balds.

Manipulation of Wildlife Habitat

Prescribed fire is used on some national forests in the southern Appalachians to improve habitat for certain wildlife species. However, it may degrade habitat for other species. Each of the hundreds of wildlife species in the southern Appalachians responds differently to fire depending upon the frequency, intensity, severity, and season of burning, as well as the particular species' adaptations to fire. To effectively use prescribed fire to benefit wildlife requires an understanding of the habitat requirements of each species. Several bibliographies and symposia have summarized results of many studies concerning effects of fire on wildlife habitat in southern forests (Lyon and others 1978; Harlow and Van Lear 1981 and 1987; Wood 1981).

Prescribed burns to improve wildlife habitat in existing stands are normally conducted in the winter (Mobley and others 1978) to avoid the spring nesting season. Deer and turkey are favored by periodic burns at about 3 to 5 year intervals. However, appropriate burning frequencies for other species are not well known. Although burning for wildlife-habitat improvement is normally associated with pine management, low-intensity burns in hardwood or mixed pine-hardwood stands are also effective because of the increased sprouting of advance regeneration and stimulation of herbaceous forage. More intense site-preparation burns can also be beneficial by increasing the abundance of legumes and other herbaceous and perennial plants preferred by many wildlife species.

Effects of Prescribed Fire

Soil

Few studies have documented the effects of fire on Appalachian soils. However, studies in other areas indicate that many factors, including fire intensity, ambient temperature, vegetation type, and soil moisture influence the effects of fire on the soil (Wells and others 1979). Low-intensity prescribed fires may improve soil fertility. Long-term prescribed burning studies in the southern Coastal Plain (McKee 1982) showed that available phosphorus, exchangeable calcium, and organic matter of mineral soil on periodically burned plots were higher than those on unburned plots. However, nitrogen was lost from the forest floor due to volatilization. Calcium and phosphorus were also lost from the forest floor but were partially leached into the mineral soil, thus remaining in the ecosystem. Annual and periodic burning on the Highland Rim in Tennessee had no affect on soil pH or exchangeable phosphorus, but did reduce soil potassium (Thor and Nichols 1974).

Prescribed understory burns normally remove only part of the forest floor. In Arkansas, Moehring and others (1966) found that a decade of low-intensity annual burnings reduced the weight of the forest floor by 64 percent. Similar results have been reported for other long-term burning studies in South Carolina (Metz and others

1961) and in Virginia (Romancier 1960). Single, low intensity burns in previously unburned Piedmont pine stands consumed about 5,000 to 6,000 lbs/ac of forest floor (Brender and Cooper 1968; Kodama and Van Lear 1980). Even high-intensity broadcast burns generally leave portions of the forest floor intact, because rarely do these types of fires burn uniformly over the entire area. Prescribed fire is a random process (Johnson 1984), and there are usually areas that fail to burn or burn only lightly, even in generally intense fires. The quantity of forest floor left unconsumed can be controlled by the prescription and execution of the burning. Broadcast burns set when the lower forest floor and soil are moist seldom consume the entire duff layer, especially when relatively fast-moving head fires are used.

Prescribed burns conducted when soil and fuel moisture conditions are too dry can cause severe damage. Broadcast burns conducted under these conditions can remove all the forest floor and cause accelerated erosion in steep terrain. Although not well documented in the South, losses of nutrients, particularly nitrogen, from this type of burning could approach losses associated with intensive mechanical site preparation and result in lower productivity.

Amounts of nitrogen volatilized during low-intensity burning in loblolly pine stands have been estimated between 20 lbs/ac (Kodama and Van Lear 1980) and 100 lbs/ac (Wells 1971). Sulfur is also volatilized during burning, but amounts lost would be small because of low concentrations in forest fuels. High intensity fires used to eliminate logging slash, which averages about 20 tons/ac following harvest of upland hardwoods, and 9 and 3 tons/ac in natural and plantation pine (Phillips and Van Lear 1984) would volatilize much larger quantities of nitrogen.

Effects of losses of this magnitude on soil nitrogen status are difficult to predict. Amounts of nitrogen in southern forest soils vary widely, but probably average about 2,000 lbs/ac (DeBell 1979), the vast majority of which is unavailable to plants. Nitrogen is continually being added to southern ecosystems. Jorgensen and Wells (1971) and Van Lear and others (1983) measured rates of 1-4 lb/ac/yr via non-symbiotic N-fixation in undisturbed pine stands on Piedmont sites. Jorgensen and Wells (1971) found nonsymbiotic nitrogen fixation rates were increased (from about 1 to 23 lb/ac/yr) by burning on poorly drained Coastal Plain soils. They suggest that burning improves those site conditions associated with a higher rate of fixation, such as more available nutrients and higher soil moisture and temperature. Nitrogen inputs from precipitation approximating 5 lb/ac/yr have been measured in the southern Appalachians (Swank and Douglass 1977) and in the upper Piedmont (Van Lear and others 1983). Over the course of a rotation, it would appear that these inputs could balance nitrogen losses from burning.

Rates of symbiotic nitrogen fixation by native legumes and non-legumes in the Appalachians have not been well documented over the course of a rotation. However, early stages of plant succession are often dominated by nitrogenfixing species, especially in ecosystems with a high fire frequency (Gorham and others 1979). Permar and Fisher (1983) found that wax myrtle, even though accounting for only 8 percent of the crown cover, fixed about 10 lb/ac/yr nitrogen in a young pole-size slash pine plantation in Florida. Boring and Swank (1984) reported that 4-year-old stands of black locust fixed about 30 lb/ac/yr in the Southern Appalachians. The abundance of annual legumes decreases rapidly as other herbaceous vegetation becomes established and the crowns begin to close.

Low-intensity burns have little, if any, adverse effect on soil erosion, even on relatively steep slopes. Goebel and others (1967) and Brender and Cooper (1968) found only minor soil losses following single prescribed burns in the Piedmont. Two low-intensity burns prior to harvest had no effect on nutrient or sediment concentrations in ephemeral streams in the Piedmont of South Carolina (Douglass and Van Lear 1983). Cushwa and others (1977) failed to detect significant soil movement in established gullies following moderately intense backing fires in mature loblolly pine stands in the South Carolina Piedmont. However, Arend (1941) reported that infiltration rates of Missouri Ozark soils were reduced by 38 percent by repeated annual burning in oak-hickory stands. Increased overland flow caused by reduced infiltration could have increased erosion, but this was not documented.

High-intensity site preparation burns conducted under conditions of high fuel loads and low moisture may damage soil by over-heating. However, when burning is done with soil moisture near field capacity, little heating damage will occur (DeBano and others 1977) Fires which burn completely to mineral soil may accelerate soil erosion in steep terrain. Such losses have not been documented in the South. The site-preparation burning program of the U.S. Forest Service on the Sumter National Forest in the mountains of South Carolina, described earlier, uses summer burns in heavy fuels with little visible evidence of soil erosion. However, if the drying period is too long, fires may burn so hot that mineral soil is exposed over much of the area, and significant erosion could possibly result in steep terrain. By felling leafed-out residuals and allowing their foliage to cure, site preparation burns can be conducted soon after soaking rains--an obvious advantage as far as soil protection is concerned.

In summary, evidence indicates that low-intensity prescribed fires have little, if any, adverse effects on soil properties and may even improve them (McKee 1982). High intensity prescribed fires have a temporary negative effect on site nutrient status resulting from volatilization of nitrogen and sulfur, plus some cation loss due to ash convection, but this appears to be short-lived as nutrient accretion is rapid. Site recovery would not be as rapid following severe fires. Effects of high intensity fires on soil physical properties are not well documented, but the infrequent (once a rotation) use of fires of light to moderate severity and the resilience of southern forest ecosystems to fire would suggest adverse effects on the soil are minor.

Vegetation

Since forest ecosystems have been subject to forest fires for millennia, some plant species have adapted to tolerate fire and many require it for their continued existence. Adaptations have taken many forms. Some trees have thick insulating bark which protects them from the scorching heat of surface fires. The lethal temperature of protoplasm is thought to be about the same for all plants. A temperature of 147°F. is instantly lethal, while at somewhat lower temperatures more time is required to kill plant tissues. Thus, the nature and thickness of the dead outer bark are critical in protecting the living inner bark and cambium from fire damage (Hare 1965).

Mature longleaf pine is well known for its resistance to fire damage because of its thick bark. Slash, loblolly, and shortleaf pine also generally survive bole scorch when they reach sapling size or larger (Komarek 1974). Virginia pine and white pine tend to have thinner bark and are more susceptible to fire damage. However, when pine trees are young, crown scorch rather than damage to the bole is the principal cause of mortality (Storey and Merkel 1960; Cooper and Altobellis 1969).

Another fire adaption of southern pines is their ability to leaf out soon after defoliation. Most southern pines larger than sapling size can tolerate a high degree of crown scorch, especially during the dormant season, with minimum effects on survival and growth (Komarek 1974). Trees are most susceptible to crown scorch during the spring when leaders are succulent. During the summer and early fall, pole-size loblolly pine can generally tolerate all but complete scorching of foliage and still recover. Lower crown classes are more susceptible to fire-induced mortality than are dominant and codominant trees (Waldrop and Van Lear 1984). Diameter growth apparently is not significantly affected when only the lower portrion of the crown is scorched and root damage in minimal (Wade and Johansen 1982).

Fire played a major role in shaping vegetation communities in the Appalachian mountains. Overstories of southern yellow pines (Virginia, shortleaf, pitch, longleaf, and table mountain) typically dominate south- and west-facing slopes (Whitaker 1956) but, in the absence of hot fires at rather frequent intervals, will be succeeded by hardwoods. Table mountain pine is adapted to maintain occupancy of these warm, dry sites because of its serotinous cones. These cones ensure a supply of seed regardless of the time of year when a fire occurs (Barden 1977), allowing table-mountain pine to successfully regenerate when cast seed of other pine species would be destroyed. Serotinous cones have also been observed in Virginia pine, although this character is not well documented. Shortleaf and pitch pines have the ability to sprout from the root collar following top-kill by fire. Fires of anthropogenic origin probably perpetuated pine in the Appalachians since, as some researchers think, lightning fires did not occur frequently enough or were not intense enough to maintain pines on these xeric sites (Whitaker 1956). Fire protection efforts of recent decades have allowed hardwoods to re-establish dominance on sites where pines once thrived.

Stands of white pine, Virginia pine, and spruce-fir are more susceptible to fire damage than other conifers. These species have thin bark, especially when young. Moreover, these species tend to support crown fires because their branches extend to near ground level.

Above-ground portions of hardwood species are not generally as resistant to fire damage as conifers, primarily because of thinner bark. Bark thickness is not as critical to hardwood survival because fires in Appalachian hardwoods normally burn in light fuels and are of low intensity (Komarek 1974). However, there are some exceptions, such as when understories of mountain laurel "explode" and produce high-intensity fires in hardwood stands. Some hardwoods develop exceptional bark thickness upon maturity. Yellow-poplar is one of the most fire-resistant species in the East when its bark thickness exceeds 0.5 inch (Nelson et al. 1933). On the Coastal Plain, most hardwood stems over 6 in d.b.h. survived after 30 years of low-intensity annual and biennial burning (Waldrop and others 1987) with little or no damage to boles.

Foresters' fear of damaging stem quality has led to the general policy of excluding fire from hardwood stands. However, evidence of damage to boles of hardwoods is primarily from the study of wildfires, which burn with higher intensity than prescribed fires. These fires often burned in the spring when trees are most susceptible to damage. Because of these early reports, fire research in hardwood stands has lagged far behind that in pine. The role of low-intensity prescribed fires in stand management and the use of higher intensity broadcast burning in promoting quality coppice regeneration deserves greater attention from fire research.

Hardwoods, while generally lacking the fire resistance of pines, have developed another adaptation to ensure their survival in ecosystems where fire is a periodic visitor. They all sprout, generally from the base of the stem or from root suckers, when tops are killed. Suppressed buds at or below ground level often survive the heat of a surface fire and sprout in response to the loss of apical dominance. Fire does little to change species composition of young coppice stands but increases the number of sprouts per stump,(Waldrop and others 1985; Augspurger et al. 1987). Although many sprouts develop from a stump, over time they thin down to one or a few per stump. Fire promotes good quality sprouts by forcing them to develop from the ground line or below; thus the developing stems tend to be free of rot and well-anchored (Roth and Sleeth 1939; Roth and Hepting 1942).

Many species have adapted to a high frequency fire regime by developing light seed, which can be wind- and gravity-disseminated over large areas. These light seeded species often pioneer on burned seedbeds. Some species, such as yellow-poplar, produce seed that remain viable for years in the duff. Yellow-poplar seed stored in the lower duff germinates rapidly following low-intensity prescribed fires (Shearin and others 1972).

Herbaceous vegetation thrives on fire-prepared seedbeds. Legumes were more abundant in young loblolly pine plantations in the Georgia and Virginia Piedmont on plots where logging slash was burned (Cushwa and others 1966; Cushwa and Reed 1966). However, single, low-intensity prescribed fires in unthinned pine stands are not likely to stimulate production of herbaceous plants, because either mineral soil is not exposed or light is limiting to germination or growth.

Fire affects not only individual plant species, but also entire communities. Community structure is altered by burning. For example, a shrub layer may be completely eliminated and replaced by a grass and forb layer if burning is frequent. The absence of fire in the long-run will favor more shade-tolerant, less fire-tolerant species and succession will proceed toward a climax community rather than a fire-maintained subclimax type (Spurr and Barnes 1980).

Periodic fires at intervals of several years favor species which are more fire-resistant than their competitors. A series of periodic fires prior to harvest of mature hardwood stands may increase the number of oaks in the advance regeneration pool (Little 1974), an important consideration in the reestablishment of stands with a large oak component. Studies in the northeast indicate that oak seedlings resist root kill by fire better than their competitors, thereby giving oak an ecological advantage (Swann 1970; Niering and others 1970). Advance regeneration of oaks in central Tennessee was doubled by both annual (for 6 years) and periodic (at 5-year intervals) pre-harvest prescribed fires (Thor and Nichols 1974). A single low-intensity prescribed fire, however, had only a slight positive effect on increasing the relative position of oak advance regeneration in the mountains of South Carolina and Georgia (Teuke and Van Lear 1982).

Intense fire in young mixed hardwood stands may favor oak, as noted by Keetch (1944) and Carvell and Maxey (1969) both of whom observed that species composition of mixed hardwood stands was converted to predominately oak by wildfire. McGee (1979) did not observe this beneficial influence of fire on oak on the Cumberland Plateau in north Alabama. Burning in both spring and fall in 5 to 6-year-old mixed hardwood stands increased only the relative dominance of red maple. Obviously much remains to be learned about the use of fire to alter species composition in hardwood stands.

Water

Effects of prescribed fire on water vary, depending on fire intensity, type and amount of vegetation, ambient temperature, terrain, and other factors. The major problems associated with prescribed fire and water quality are potential increases in sedimentation and, to a lesser degree, increases in dissolved salts in streamflow (Tiedemann and others 1979). However, most studies in the South indicate that effects of prescribed fire on water quality are minor and of short duration when compared to effects of certain other forest practices.

Brender and Cooper (1968) noted that repeated low-intensity prescribed fires had little effect on hydrologic properties of soils in the Georgia Piedmont. Douglass and Van Lear (1983) monitored water quality of ephemeral streams following two low-intensity prescribed fires in Piedmont loblolly pine stands and detected no significant effects on suspended sediment.

The key to the minimal impact of burning on water quality in these studies is the low to moderate intensity of the fires. Even though the terrain was relatively steep, erosion and sedimentation were not increased. Douglass and Goodwin (1980) have shown that in steep terrain the increase in suspended sediment following management practices is generally related to the amount of bare soil exposed. This would be especially true if the root mat is destroyed by disking or blading. Low intensity flames (1-4 foot flame length) normally will consume less than half of the forest floor, and if mineral soil is exposed it is only in small isolated patches in the burned area.

Ursic (1970) measured sediment output from site preparation burning in north Mississippi. Although sediment levels on burned watersheds were several-fold greater than those of control plots, sediment output was only about 0.5 ton/ac/yr.

Only a few studies in the South have documented effects of prescribed fire on nutrient response in streams or ground water. Douglass and Van Lear (1983) in the Piedmont and Richter and others (1982) in the Coastal Plain failed to detect any major impact on stormflow or soil solution nutrient levels in response to low-intensity prescribed fire. No studies in the South have examined effects of high-intensity slash burning on streamflow nutrient levels. Neary and Currier (1982) reported no adverse effects to water quality after a severe wildfire in heavy fuels in the Blue Ridge Mountains of South Carolina. A summary of the effects of fire on water (Tiedemann and others 1979) showed that in several cases slash burning in the western United States increased nitrate-N levels in streamflow. In no case did burning cause nitrate-N levels to exceed the recommended EPA standard of 10 parts per million for drinking water. Phosphorus and major cations often increase in streamflow and the soil solution following intense slash fires, but the effects are of short duration and of a magnitude not considered damaging to surface waters or site productivity (Tiedemann and others 1979).

Nutrient loss and stream sedimentation in response to prescribed burning are likely to be of minor impact compared to mechanical methods of site preparation when fires are conducted properly. Even under intense broadcast burns the root mat may be little disturbed and its soil-holding properties left intact. Furthermore, slash tends to be randomly distributed over logged areas and is seldom completely removed by broadcast burning. Therefore, the root mat, residual forest floor materials, and incompletely consumed slash form debris dams which trap much of the sediment moving downslope (Dissmeyer and Foster 1980). Also, rapid regrowth in the South quickly provides site protection.

Despite speculation that effects of intense prescribed fires are minor on soil and water resources, research is needed to document the magnitude and duration of such fires, especially in the steep terrain of the Piedmont and mountains.

Air

The risk of smoke movement into sensitive areas such as airports, highways, and communities is probably the major threat to the continued use of prescribed burning. Particulates are the major pollutant in the smoke from prescribed burning (Dieterich 1971; Hall 1972; Sandberg and others 1978). They are complex mixtures of soot, tars, and volatile organic substances, either solid or liquid, and average about 0.1 micron in diameter (McMahon 1976). With low wind speeds and high humidity, particulates serve as condensation nuclei and result in dense smoke or combinations of smoke and fog. Reductions in visibility during and after prescribed fires have caused numerous highway accidents.

Smoke often accumulates in depressions or along stream channels and other low-lying areas. When the relative humidity approaches 90 percent, which is common during many nights, fog formation is stimulated by the presence of smoke. The combined effects on visibility of smoke and fog is far greater than that of smoke alone. Even smoke from a smoldering fire days old can seriously impair visibility miles away from its origin under certain atmospheric conditions.

Particulates are not the only emissions from fire. Besides carbon dioxide and water vapor, gaseous hydrocarbons, carbon monoxide, and nitrous oxides are also released (Chi and others 1979). However, only a small proportion (0-3%) of the total national emissions of particulates, carbon monoxide, and hydrocarbons can be attributed to prescribed burning.

Carbon monoxide is a poisonous gas which may reach moderately high levels above and adjacent to prescribed fires, but these concentrations decline rapidly with increasing distance from the flame (McMahon and Ryan 1976). By burning under atmospheric conditions which encourage rapid mixing, the problem of high carbon monoxide levels can be eliminated.

Hydrocarbons are a diverse group of compounds which contain hydrogen, carbon and their oxygenated derivatives (Hall 1972). Unsaturated hydrocarbons result from the incomplete combustion of organic fuels. Because of their high affinity for oxygen, these compounds may form photochemical smog in the presence of sunlight and oxygen-donating compounds. Methane, ethylene, and hundreds of other gases are released in prescribed burning. Some of these compounds are known to be carcinogeni to laboratory animals, but there is no evidence to show that prescribed fire is increasing these compounds in the environment to dangerous levels. Most of the hydrocarbons released during prescribed fires are quite different from those release in internal combustion engines.

Nitrogen oxides are not likely to be released in significant quantities during prescribed burning. Most forest fuels contain less than 1 percent nitrogen, of which 20 percent is converted to nitrogen oxides when burned (National Wildfire Coordinating Group 1985). Sulphur dioxide emissions from prescribed fires are of minor importance since sulphur concentration of most forest fuels is less than 0.2 percent (USDA Forest Service 1976).

Because of the serious nature of the effects of prescribed fire on air quality, and its concomitant value as an essential forest management tool, smoke management guidelines have been developed by the U.S. Forest Service to reduce the atmospheric impacts of prescribed fire (USDA Forest Service 1976). This system consists of five steps: (1) plotting the trajectory of the smoke; (2) identifying smoke sensitive areas such as highways, airports, hospitals, etc.; (3) identifying critical targets, i.e., targets close to the burn or those which already have an air pollution problem; (4) determining the fuel type to be burned, e.g., whether the fuel load is light as with a mature pine stand with a grass understory, or heavy as the logging slash following clearcutting; (5) minimize risk by burning under atmospheric conditions which hasten smoke dispersion, or by using appropriate firing techniques and timing to reduce smoke pollution.

Objectives for prescribed burning should be compatible with air quality laws and regulations and should consider both on- and off-site environmental impacts. Plans should be made to notify fire-suppression organizations, nearby residents or businesses, and adjacent landowners of the intent to burn. Should wind direction change, burning crews must be prepared to control traffic on affected highways and extinguish the fire if necessary.

The impact of smoke can be reduced by burning under proper weather conditions. The fire manager should have current weather forecasts with enough information to predict smoke behavior. Both surface weather and upper atmospheric conditions are important. Burning should be conducted when wind is moving away from sensitive areas such as highways and homes. The atmosphere should be slightly unstable for optimum smoke dispersal without loss of fire control. Burning at night should be avoided because visibility is poor and because weather and smoke behavior are more difficult to predict.

On the day of the burn, the fire manager should check with pollution control agencies about pollution alerts or temperature inversions. If none exist, a small test fire should be set to determine the direction and behavior of smoke. Areas next to roads should be burned quickly and when road use is low; mopup (the work required to completely extinguish all fire) should follow as soon as possible to reduce smoke hazard. Where possible, burning should be conducted in small blocks and with backing fires to minimize the volume of smoke produced.

Conclusions

Information regarding the use of prescribed fire in Appalachian ecosystems is limited. However, the few pertinent studies in the Southern Appalachians, as well as studies from other physiographic regions, suggest that prescribed fire could be an important management tool. Low-intensity prescribed fires are used in pine management to prepare seedbeds, control understory hardwoods, reduce wildfire hazard, and improve wildlife habitat. Higher-intensity fires are necessary to prepare sites for planting.

Single prescribed fires have little effect on the species composition of advance regeneration. Since oaks have better survival rates than other hardwood species after repeated burning, periodic prescribed fires may be used to control competing vegetation and favor advance oak regeneration. Although many foresters are justifiably concerned about stem quality of valuable hardwoods, evidence suggests that low-intensity fires in light fuels during the dormant season have little adverse effect on large trees.

If fire is shown to benefit oak regeneration on better sites, prescribed burning may gain added impetus as a forest management tool in the southern Appalachians. Therefore, foresters will need a better understanding of fire uses, and intensive efforts to educate the public regarding prescribed fire as a management tool in mountain terrain will be required.

Mixed pine-hardwood stands are being successfully regenerated following clearcutting in the southern Appalachians with properly timed felling of residuals and broadcast burning. Broadcast burning greatly reduces debris to facilitate planting and allows planted pines to successfully compete with hardwood coppice. A single post-harvest burn does not affect species composition of coppice regeneration, but additional research may show that periodic post-harvest burning may increase the oak component.

Environmental effects of prescribed fire in the steep terrain of the southern Appalachians depend primarily on fuel and weather conditions when burning is conducted. Even high-intensity broadcast burns conducted when fuel and soil moisture conditions are appropriate have little effect on soil erosion and hydrologic functioning of mountain ecosystems. Research is lacking concerning nutrient cycling effects of burning in these systems.

Both low- and high-intensity prescribed fires can benefit several wildlife species by increased sprouting of nutritious and palatable stems. In addition, burning often increases herbaceous forage and associated insect populations for the benefit of certain species of wildlife.

Air pollution resulting from prescribed burning is a concern, especially in the terrain of the Appalachians. Population density may also limit the potential of this management tool. The utmost care in conducting burns in accordance to smoke management guidelines is essential if burning is to become a part of forest management in Appalachian hardwoods.

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Draft Environmental Impact Statement

United States
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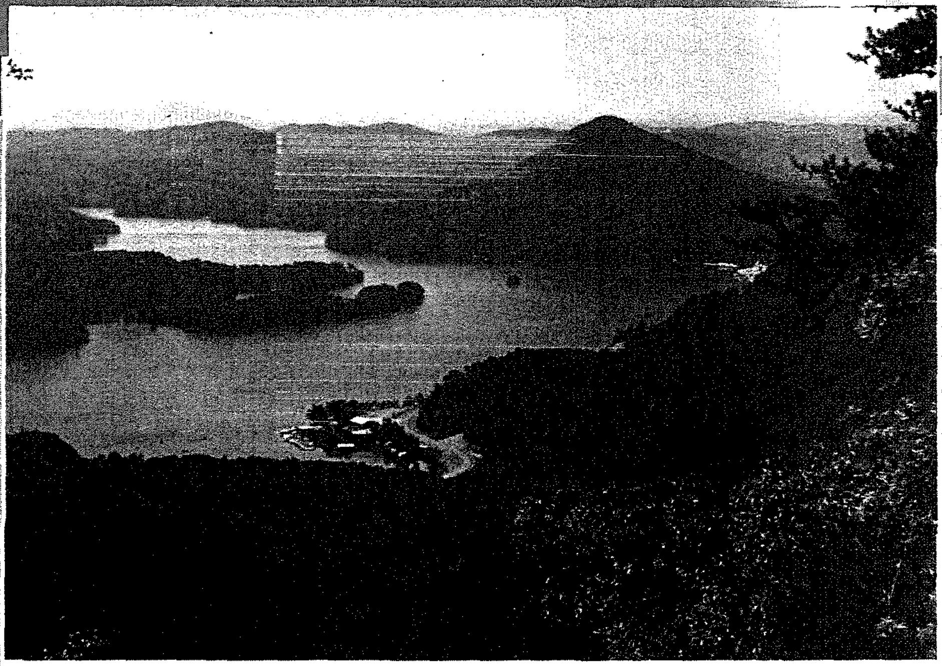
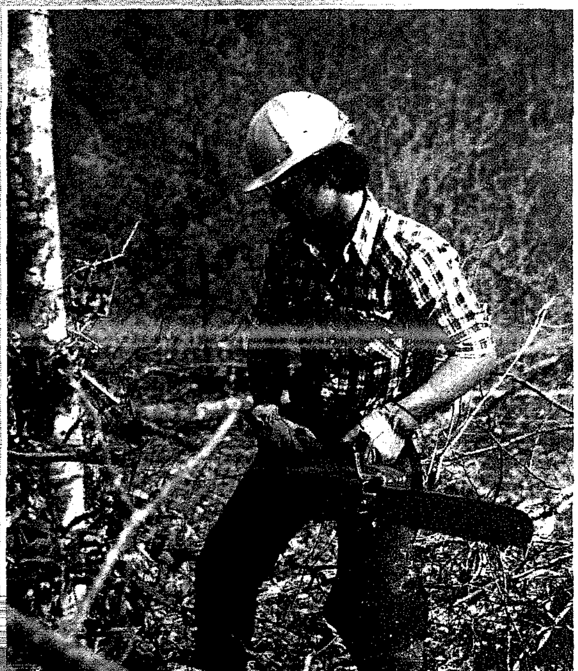
Forest Service
Southern Region

VEGETATION MANAGEMENT in the Appalachian Mountains

APPENDICES VOLUME II





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